NASA SCIENCE MISSION DIRECTORATE

EARTH-SUN SYSTEM DIVISION

APPLIED SCIENCES PROGRAM

Public Health Applications of Earth-Sun System Science Results

ArboNET/Plague Surveillance System

The focus of this project is to evaluate, verify, validate, and benchmark Earth-Sun system science observations and models as indication and warning tools (I&Ws) within the ArboNET /plague surveillance system (PSS) of the Center for Disease Control and Prevention. The increased spatio-temporal resolution of these environmental I&Ws is expected to greatly enhance the performance and timeliness of the ArboNET PSS.

Goddard Space Flight Center Project Plan: FY2005-FY2008

10 February 2005

Version 1.0

Expanding and accelerating the realization of economic and societal benefits from Earth-Sun System science, information, and technology

Table of Contents

1. Purpose & Scope

Plague is an infectious disease usually transmitted to people by rodents whose fleas carry the plague bacterium *Yersinia pestis*. Plague surveillance is a CDC priority because it is a Class A disease and, by law, all occurrence of cases or suspected cases must be reported. Plague surveillance has been identified as a top priority for this and coming generations, and for all countries. Plague is also monitored for its potential as a bio-terrorist agent.

Although the times of devastating pandemics of "black death" have long disappeared with improved sanitary standards and extended medical knowledge, outbreaks in people still occur in rural communities or in cities. The affected regions are Central and South Asia, large parts of Africa, South America and parts of the U.S. Plague was introduced into North America via San Francisco, California, in 1899-1900 by shipboard transport of plague-infected rats from Asia. These rats quickly infected native mammal populations and plague spread throughout western North America. The last epidemic in the United States occurred in Los Angeles in 1924-25. Since then, human plague in the United States has occurred as mostly scattered cases in rural areas (an average of 10 to 15 persons each year). Globally, the World Health Organization reports 1,000 to 3,000 cases of plague every year. Most human cases in the United States occur in two regions: 1) northern New Mexico, northern Arizona, and southern Colorado; and 2) California, southern Oregon, and far western Nevada.

Plague prevention and response efforts are underway at regional, state and local levels through the Center for Disease Control and Prevention (CDC)-sponsored ArboNET/Plague Surveillance System (PSS). ArboNET is a passive surveillance system managed by the division of vector-borne infectious diseases at CDC to collect and archive data to study and operationally monitor regional and national arthropod-borne viral disease trends. The CDC, participating health departments, Department of Defense (DOD) and the US Geological Survey (USGS) are primary users of ArboNET. A basic understanding of the area's landscape ecology is useful for predicting the future course of epizootics and identifying areas of high risk for humans. Information should be collected on predominant vegetation types and the amount of local land surface covered by each vegetation type, roads, railways, airports and seaports, land use patterns (agricultural, residential, industrial, other), types of dwellings present and whether these dwellings and associated food storage areas or other man-made sites provide food and harbor for rodents. The incorporation of Earth-Sun system science satellite observations and model predictions into the ArboNET/PSS is intended to improve their accuracy with regard to spatial and temporal dimensions of plague vector habitats. This improvement will enhance the "representativeness" attribute of PSS.

In response to this need for more spatially and temporally complete information, CDC has partnered with NASA to explore the use of remote sensing products and to employ different remote sensing models and techniques. A few pilot studies are now underway in certain regions of New Mexico, Arizona, and Colorado (four corners states) to evaluate, verify and validate a remote sensing prototype NASA product that uses satellite datasets and models compiled by the Global Inventory Mapping and Monitoring Studies (**GIMMS**) group at NASA/GSFC. The data set includes products from the AVHRR instrument on six NOAA platforms (7-9-11-9-14-16-17), from the MODIS sensors aboard the EOS Terra and Aqua Satellites, LandSAT TM data, Shuttle Radar Topography Mission (**SRTM**), and Tropical Rainfall Measuring Mission (TRMM), among other remote sensing platforms provided by NASA and NOAA. A crucial and unique feature of the compiled data set is that an NDVI data has been intercalibrated from the AVHRR, SPOT Vegetation, and MODIS instruments. Thus, should one or more of the NDVI-providing instruments fail, we can switch to another source of NDVI and/or thermal data. Furthermore, because we have intercalibrated the AVHRR NDVI time history back to 1981, we can use a 24-year global NDVI time series to provide environmental indications of past potential epidemics and to understand the severity of the outbreak vis-à-vis the historical record back to July 1981. In fact, by comparing proxy vegetation response patterns, as detected by the intercalibrated remotely sensed NDVI, a model has been developed by the GIMMS group to provide a set of indications and warnings that reveal unusual climatic conditions associated temporally and spatially with trigger points of infectious and vector-borne diseases such as ebola, rift valley fever, and plague epidemics.

Climate variability is thought to affect a number of infectious diseases. In particular, the Trophic Cascade Hypothesis (TCH) was developed to explain changing levels of human risk for zoonotic diseases associated with climate variability in the US Southwest. However, the role of weather and ecological/environmental mechanisms by which human health is impacted by climate variability presently is not well understood. When the TCH modeling system is applied to forecast plague outbreak conditions two different triggering mechanisms are observed. Depending on the region, a bimodal (May and July) or unimodal (August) peak dynamics is found. Rodents' movements also play an important role in the plague dynamics, complicating the system. Rodents can move down slopes, from higher elevations to lower elevations; plague does the same. Thus, products derived from Earth observing instruments, technology, and science information that consider not only vegetation dynamics, but also elevation, slope, aspect, and land cover diversity in their models will provide information on plague vector habitats enabling ArboNET to better characterize outbreak conditions and enhance its PSS.

Remote-sensing and enhanced observation-based products and models are currently being evaluated and will be verified and validated as inputs to CDC's ArboNET/PSS by the end of FY06. By collaborating with CDC national and regional offices and their partnering agencies, e.g. USGS and NOAA, we aim to address an identified need for space-based ecological monitoring, prediction, and decision support infrastructure for ArboNET/PSS. We benchmark our approach by examining the CDC's ArboNET/PSS in the four corners region. A benchmark report is planned for no later than FY07. We make probabilistic predictions of warnings based on the climatic-environmental indications together with uncertainties and estimates of error. This project is an important contribution to NASA's expanding emphasis on the Applied Sciences program in public health and their socio-economic benefits. The ArboNET/PSS project is driven by a scientific research thrust that uses the most relevant and powerful data and modeling techniques available to effectively quantify and document environmental plague risk factors.

2. Project Goals & Objectives

The main goals of this collaborative project are to provide 1) earth-sun system science satellite observations and model predictions on plague vector habitats and 2) mathematical modeling results designed to investigate the role of climatic factors in the changing frequency of human plague cases in the American Southwest that will enable ArboNET to improve detection of outbreaks and better identify areas and conditions associated with increased human plague risk. The needs of the CDC regional centers involved in plague surveillance will be met with different satellite observations such as MODIS products (e.g. vegetation vigor, fractional tree cover, and land cover changes, etc.), LandSAT imagery, SRTM, and TRMM. In addition, other sensor products may be evaluated to see what may be considered “value-added” to CDC's PSS and the control/prevention decision-making process. The use of these datasets will be further enhanced by assimilating them into the GSFC/GIMMS disease ecoclimatic link algorithm for forecasts of outbreak conditions. Both retrospective studies and near real-time simulations will be evaluated and made available to investigate the responses of rodent food resources (plant cover and net primary production), and rodent/vector reservoir abundance to meteorological events.

The ArboNET/PSS project is organized around of three components: engineering, science, and communications. These three elements are working together (1) to establish and begin implementing a plan to verify the identified mission data, models and technology as plague surveillance solutions (FY04), (2) to characterize ecological and environmental conditions and features in areas where bubonic plague outbreaks have occurred (FY05), to produce FY05-08:

(3) on demand, predictive (in space and time) landscape- and regional-scale maps for monitoring plague trends and outbreaks, (4) data integration and modeling capabilities with an emphasis on NASA's unique remote sensing, computational, and engineering resources that can contribute to plague surveillance, and (5) an interagency partnership that will ultimately allow CDC to deploy these new capabilities operationally in support of CDC plague science and management decision making. Following a systems engineering approach, the project will produce a verification and validation report in FY06. This report will be followed by an ArboNET/PSS benchmark report in FY07. The project is expected to be completed within five years. The knowledge gained and technology developed for these efforts are also intended to be transferred to other decision support systems requiring such capability, pending the success of the projects and available future funding.

3. Project Team

The appropriate NASA science, engineering, and data teams held a meeting in 2003 with CDC National Center for Infectious Diseases, Division of Vector-borne Infectious Diseases in Fort Collins, to evaluate specific requirements for the Plague Surveillance System component of ArboNET. The products of these meetings included feasibility analyses for integrating specific Earth Science mission observations and models, e.g. the GSFC/GIMMS disease ecoclimatic link algorithm, as well as a description of the state-of-the-art of Earth observation technology that may be applied to plague surveillance solutions. University partners will also work with NASA and project partners to directly evaluate, verify/validate and benchmark the utility of NASA data into partner PSS.

Program Managers: John Haynes (HQ) and Shahid Habib (GSFC)

Project Manager: Compton J. Tucker

Project Team Members: Jorge E. Pinzon, Jennifer Small, and Molly E. Brown

NASA Center Participation: Stennis Space Center: Vaneshette Henderson

Project Partners: CDC: Kenneth L. Gage, Russell E. Enscore, and John A. Montenieri

4. Roles and Responsibilities

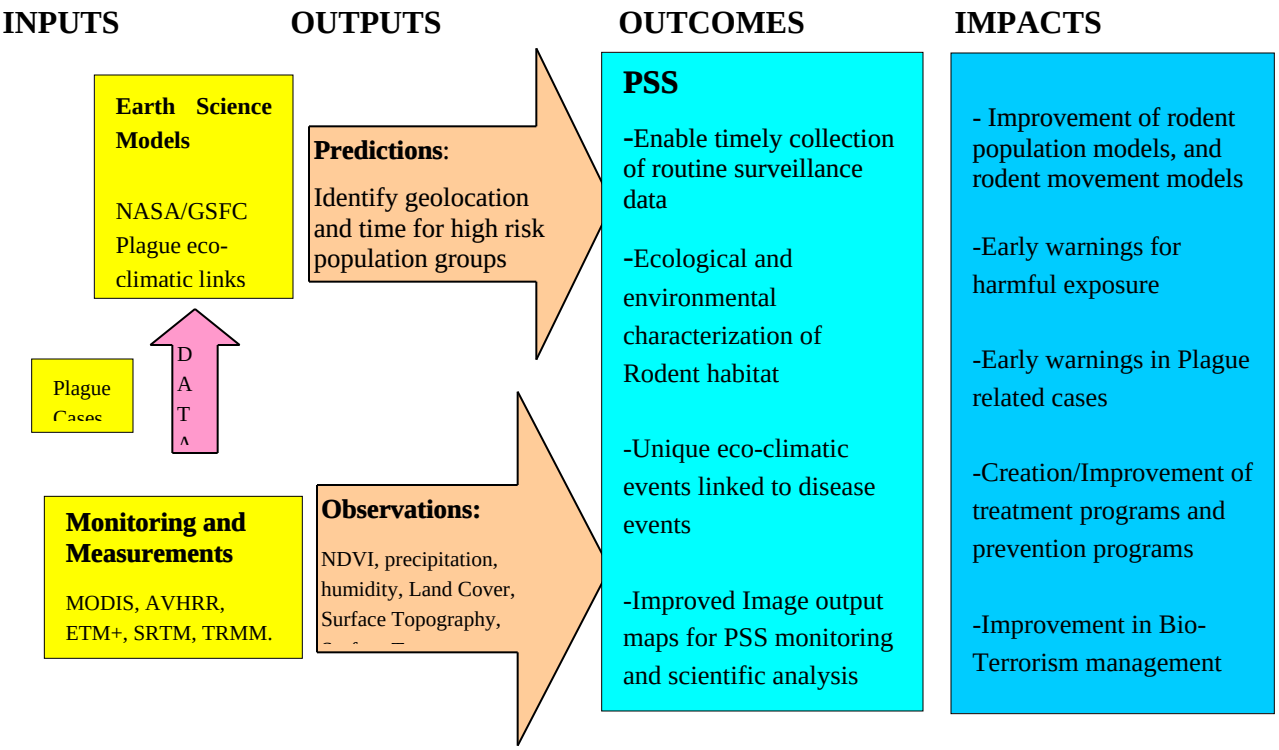

Figure 1. Integrated system solution diagram for incorporation of NASA remotely sensed and modeling products to enhance the CDC Plague Surveillance System component of ArboNET.

The NASA-GSFC team (Compton J. Tucker, Jorge E. Pinzon, and others) will collect and process existing satellite and ancillary data required for this project. In addition, such data will be integrated into the GSFC disease ecoclimatic link algorithm.

The NASA-GSFC team will work with teams from CDC located both in Fort Collins and area offices, to collectively undertake exploratory studies of bubonic plague and climatic conditions in the 4-corners region. Also the NASA-GSFC team will utilize and analyze the state-of-the-art of Earth observation technology (e.g. Satellite-derived normalized difference vegetation index (NDVI) with in-house tools to determine the correspondence between every possible reported outbreak and the calibrated long time series (1981-date) of satellite NDVI record. This procedure will allow the characterization and stratification of bubonic zones by their temporal/spatial distribution.

The CDC team (Kenneth Gage, Russell Enscore, and others) will develop and customize their PSS tools and models, and make available to the NASA GSFC team the most comprehensive list of all possible bubonic plague occurrences in the format of: (i) case or index number, (ii)

latitude, (iii) longitude of case exposure, and (iv) date of documented case onset. Also the CDC team will set up their operational systems to ingest and archive the NASA products to be used in their PSS for near real-time operations and retrospective studies.

5. Project Implementation and Approach

Figure 1 shows the approach for integrating remote sensing information system components to be evaluated for use in ArboNET/PSS and modeling tools of the CDC. We have broken down the input driving variables to the ArboNET PSS tool into atmospheric, weather and vegetation dynamics, Land Use/Land Cover variables, and topography. There is also shown an 'in-situ' comprehensive list of plague occurrences being routed from CDC to NASA GSFC to be integrated into the GSFC plague algorithm. The GSFC plague algorithm will be customized according to the PSS operations to be more in-line with their CDC modeling systems. Also, a MODIS-AVHRR NDVI datasets integration and other remote sensing observation products are highlighted as part of the process. This work has significant overlap with other federal agency decision support tools and where possible we may readily provide significant support to USGS, DoD, and NIH.

Evaluation: Working with project partners, we are producing an evaluation report on the specific requirements for the Plague surveillance system component of ArboNET. This should include a feasibility analysis for integrating specific NASA Earth-Sun system science mission observations and models as well as a description of the state-of-the-art of Earth observation technology that may be applied to plague surveillance solutions. For each category, we have listed the relevant specific parameters, and finally, their projected source.

	Earth-Sun System Science Results	**Source**
Atmospheric and Weather	Precipitation Temperature Humidity	TRMM MODIS MODIS
Vegetation **Land Use/ Land Cover** **Topography**	Habitat quality Land Use Surface Topography	AVHRR/MODIS NDVI MODIS/LANDSAT SRTM
In-situ calibration	List Plague Cases	CDC spreadsheet
Relevant Earth-Sun System Science Modeling Efforts (relevant in Public	Visualization technology Outbreak indications and warnings	GIMMS visualization tools GIMMS Disease Eco-climatic algorithm

Health)		

Verify and Validate: while the general GSFC/GIMMS disease eco-climatic link algorithm has been validated in other vector-borne diseases, it has not previously been applied to plague. This algorithm is being customized for plague surveillance. It will receive new remote sensing data (land cover, topography, precipitation, humidity) to adjust to rodent movement from higher elevation to lower elevations. We will use a control data set from the Reservation plague cases where non-plague data go with the plague data points to verify and validate the performance of the GSFC plague algorithm when an integrated NDVI from MODIS-AVHRR datasets is used as input. Relative to data availability and timeliness in delivery, we have direct access to key Earth-Sun system science satellite observations at Goddard and could use these data for the prototype demonstrations. A verification and validation report is planned in FY06.

Benchmark: A first benchmarking at the 8km resolution will be made comparing ArboNET current PSS and ArboNET/PSS using NASA data and algorithms. Once this initial validation and benchmarking at the 8km resolution are completed, the assimilation of MODIS land surface temperature, vegetation cover and phenology measures, and LandSAT land class information will be made with selected subregions at sub-1km resolutions. A new benchmarking will be made comparing the three models: current PSS, PSS with 8km NASA data, and PSS with 1km NASA data. A benchmarking report is planned in FY07.

6. Deliverables

NASA will also work closely in conjunction with CDC researchers to evaluate, verify/validate and benchmark NASA products in to ArboNET /PSS.

Evaluation: The evaluation report is being produced during this first year of the project. This report will describe the requirements of the PSS and the potential of NASA contributions with expected support from Stennis Space Center Systems Engineering. The second deliverable will be the validation of NASA products used in the results of the current ArboNET PSS and GSFC plague systems for the 4-corners region at approximately 8 km spatial resolution and a temporal resolution of 15-day time steps, using the numerical tools developed at GSFC and the integrated NDVI derived from MODIS-AVHRR fusion. These will specifically include precipitation data from TRMM and land surface topography from SRTM to better characterize eco-climatic conditions of the region. The forcing variables, state variables (e.g., vegetation and climatic conditions), and certain parameter files (e.g., MODIS land cover classes) will be verified with ETM land cover classes. This first deliverable will be presented as a report and presentation for NASA/HQ and CDC division of vector-borne infectious diseases.

Verify and validation: When this phase begins, the data products will be the next major deliverables to the CDC division of vector-borne infectious diseases and regional offices. This first prototype will be verified and validated in their PSS. This stage is planned to begin by the third month of 2005 through the second quarter of 2006. We will establish value-added measures that can be used for further studies, and feedback on products that do not add value will be further investigated. The goal by the end of the second year is to identify from the prototype which products add value and produce a metric to measure value (for benchmark) to their PSS and decision-making operations.

Benchmarking: In years 3 and 4, the goal is to use the metrics developed during 2005-2006 to measure value and benchmark the expected enhance PSS with the NASA products. In these stages, the features of simplicity, flexibility, acceptability and timeliness will be addressed. Once this initial benchmarking at the 8km resolution are completed, the assimilation of MODIS land surface temperature, vegetation cover and phenology measures, and LandSAT land class information will be made with selected subregions at sub-1km resolutions. A new benchmarking will be made comparing the three models: current PSS, PSS with 8km NASA data, and PSS with 1km NASA data. These results will be presented as a report and a presentation for NASA/HQ and CDC division of vector-borne infectious diseases.

Also, we plan to accomplish the following: provide collaborative and complete reports of how each full system works for each region of interest, including a user's manual to help them set up and maintain the system locally. All publications, scientific articles in refereed journals, and conference presentations at various international conferences will be approved by Dr. Gage or another CDC team member designated by Dr. Gage.

7. Schedule & Milestones

The following tasks define the schedule and the milestones:

- Evaluation report on the selected regions for testing (FY05)
- Compare PSS results with measured data (existing benchmark) (FY05)
- Design V&V procedures (FY2005)
- Modify models to ingest GSFC Plague algorithm and data products (FY05)
- Initialize and execute ArboNET PSS using NASA GSFC Plague outputs (FY05)
- Identify procedures and metrics to continuously benchmark impacts of new GSFC algorithm inputs on efficiency and effectiveness of forecast plague outbreak conditions (FY06-08).

- Continue to enhance and improve accuracy and assess uncertainty in GSFC algorithm and model predictions relevant to ArboNET PSS inputs to decision-making (FY05-08)
- Provide CDC with ArboNET/plague products and model parameters from satellite data (FY05)
- Incrementally test the values of each of the NASA input products (FY05) and prepare Benchmark Reports from GSFC group.
- Verify, and validate the incremental NASA products used in the results of each combination in the DSS (FY06-07)
- Benchmark the results of each incremental contribution (FY06-08)
- Benchmark combinations of NASA developed inputs (FY07-08)
- Benchmark the NASA inputs with respect to cost improvements, time improvements, accuracy, filling a need, and socioeconomic impact (FY07)
- Formalize procedures into the existing ArboNET PSS for future applications (FY08)

8. Budget

The following table provides the estimated budget needs for this project.

Budget summary by task

	FY2004	FY2005	FY2006	FY2007	FY2008
Initial Evaluation, Epidemiological data gathering and organization from CDC records, application of GSFC plague algorithm using intercalibrated MODIS-AVHRR, NDVI data sets	90.68K				
Develop PSS and higher scale satellite products for evaluation. Incrementally test results		83.5K			
Verify and validate results of each improvement to the NASA model. Test combinations of inputs.			182K	145K	120K
Benchmark results and formalize methods.				134K	170K
Workshop thru SSAI			12K		
Manuals, publications				16K	
Travel	5K	2K	11K		
Hardware, software, etc	5K	5K	20K		
Management	29K	23.25K	110K	135K	140K
Taxes	13.32K	11.25K	36K	45K	45K
Totals	143K	125K	361K	475K	475K

Consolidated full cost entry

		FY04	FY05	FY06	FY07	FY08	Total
1000	Personnel	0.0	27.3	27.9	29.6	31.0	115.8
2100	Travel	5.0	2.0	11.0	0.0	0.0	18.0
3000	Procurements	143.0	125.0	361.0	475.0	475.0	1,579.0
8005	Center G&A	75.0	80.3	134.1	200.8	199.7	689.9
8020	Service Pools	27.4	30.9	49.5	74.1	70.7	252.6
	Total NOA	250.4	265.5	583.5	779.4	776.5	2655.3

9051	Civil Servant FTEs	0.2	0.2	0.2	0.2	0.2	1.0
9052	On-Site Contractors WYEs	1.6	1.4	2.5	3.9	3.6	12.9
9053	Center G&A Civil Servant Service FTEs	0.4	0.3	0.6	0.8	0.8	2.8
9055	Service Pool Civil Service FTEs	0.1	0.1	0.1	0.1	0.1	0.4
9056	Service Pool Civil Service FTEs	0.0	0.0	0.1	0.1	0.1	0.3

9. Exit Strategy/Transition Plan

The most important requirement for moving our work to operational status is the sustainable support that the CDC itself is providing. At the end of the project implementation, the aim is to have a number of products that will be operationally generated in near real-time (and a plan established to transfer the customized operational systems to CDC). All products will be provided by CDC to the appropriate PSS through the Internet for easy accessibility.

The major products we plan to provide will include the following:

- Temporal risk maps of bubonic plague occurrence (latitude, longitude, time).
- Spatial distribution maps of bubonic plague occurrences (latitude, longitude).
- Spatial and temporal characterization (maps) of common ecological and climatic features in areas of plague outbreaks.
- Changes in vegetation dynamics and parameters related to land use and cover classifications, affecting regions of plague outbreaks.
- Integration of gridded GSFC plague information into ArboNET/PSS monthly to quarterly operational decision support applications (to begin in FY04 and continue through the project).
- Verify and validation of four and eighth month forecasts of GSFC plague information and predictions of extreme climatic plague-trigger events and normal conditions.

10. Performance Measures

Various strategies will be used to monitor progress for this project. These include:

- Formal briefings to NASA-HQ every six months to report progress and to review project.
- Monthly technical team meetings (within individual teams) or teleconferences (between the teams) to assess project task status.
- Continuous field application of GSFC plague algorithm products to improve PSS for decision-making, which will provide quantitative assessments of value added by the new information in terms of early warnings of harmful exposure.
- Benchmarking of value added to PSS decision-making in terms of early warnings in Plague related cases and improvement of prevention programs.
- Project review meetings held every year between the partners (NASA-GSFC and CDC) to communicate progress and leverage activities and results.

- Direct interaction with satellite and ancillary data providers and other workers through meetings, seminars, and workshops in order to re-evaluate (and if necessary re-calibrate) our strategies and methods vis-à-vis prevailing scientific trends and results.
- Direct interaction with industry and potential users of our products to communicate our development strategies and results and understand system performance and requirements.
- Peer-review of technical manuscripts developed by project team members.

Signature Page

This document contains the ArboNET/Plague project plan for collaborative efforts with the Center for Disease Control and Prevention (CDC) beginning FY2005 through FY2008.

_____. _____.

Compton J. Tucker Date
ArboNET/Plague Surveillance System Project Manager
NASA Goddard Space Flight Center, Code 614.4
Greenbelt, Maryland 20771

_____. _____.

Shahid Habib Date
NASA/GSFC Applications Program Manager
NASA Goddard Space Flight Center, Code 600
Greenbelt, Maryland 20771

_____. _____.

John Haynes Date
Program Manager, Public Health Applications
NASA Science Mission Directorate
Earth-Sun System Division
Applied Sciences Program
NASA Headquarters, Washington, DC